R. P Note No. 72

Estimates of Skyshine from Loma Linda Accelerator in IB1

W. S. Freeman

May 17, 1988

I. Introduction

This note describes some estimates of the dose rates due to neutron skyshine from the Loma Linda Synchrotron in IB1. Skyshine is extensively discussed in several papers listed in the references. Refer to these for details of the various parametrizations.

II. Methods

Neutron skyshine has occasionally presented problems at proton accelerators that had very thin roof shielding. Thomas, for example makes the general statement that "some overhead shielding is required for accelerators that produce neutron intensities greater than about 10^9 neutrons per second" [1]. By skyshine, I mean the dose resulting from neutrons that are emitted in a upward direction and then scatter from air molecules back down to a measurement location.

There are many measurements at different accelerators of "skyshine". Unfortunately the experimental conditions are often not under the control of the health physicist doing the measurements. In addition the shielding arrangement often is not optimized, the neutron source term is not well known, and instrumentation varies, making it difficult to use this information in the design of another facility. Nevertheless there are several parameterizations of the dose that allow one to make at least "order of magnitude" estimates of the doses due to skyshine.

I have used several of these expressions to estimate the skyshine dose expected during normal running of the Loma Linda accelerator in IB1. Most skyshine formulae assume that one is interested in the dose at large distances (typically hundreds of meters). The dose (or fluence) attenuation is primarily determined by the increasing distance from the source (r^{-2}) and an exponential factor due to scattering and absorption ($\exp(-r/\lambda)$). The attenuation length, λ, may depend on the neutron energy. Note that we are interested in the dose close to the source (e.g. in the accelerator control room area) as well as at larger distances. These formula are of questionable usefulness at distances comparable to or less than the size of the neutron emitting "source". For IB1 this probably means 10 meters or less (the size of the accelerator enclosure). At very small distances there will be shadowing effects from the shield wall and a strong dependence on the location of the loss point relative to the measurement location. Keeping all these caveats in mind, I plunge ahead.

A. Expression 1

Taken from Ref 2. the dose from skyshine, H, at a distance r from the source is

$$H(r)=3\times10^{-10}\exp(-r/\lambda)/r^2$$

where H is in mrem per neutron emitted and r is in meters.

$\lambda = \lambda(E)$ -----> for E=250 MeV, λ=520 meters

I assume:

a) 2.5×10^8 protons per second (1% loss)
b) 1 neutron per proton [see ref 1, figure 3.22]
c) 0.5 of all neutrons emitted into upper hemisphere

Dose rate at 10 meters is:

H(10 meters)=$3\times10^{-10}\exp(-10/520)/100 \times (1.25\times10^8$ neutron/sec)x(3600 seconds/hr)
H(10 Meters)=**1.3 mrem/hr**

Dose rate at 100 meters:

H(100 Meters)=$3\times10^{-10}\exp(-100/520)/10000 \times (1.25\times10^8$ n/sec)x(3600 sec/hr)
H(100 meters)=**0.01 mrem/hr**

B. Expression 2

Taken from Ref 2 (Lindenbaum formula):

$\phi(r)=1.4\times10^{-5}\exp(-r/25000)/r \times (1.25\times10^8$ n/sec)

where ϕ is the neutron fluence at a distance, r, with ϕ in units of neutrons $cm^{-2}\ sec^{-1}$ and r in cm.

ϕ(10 meters)=1.7 n $cm^{-2}\ sec^{-1}$

For 1 MeV neutrons, there are 8.5 n $cm^{-2}\ sec^{-1}$ per mrem hr^{-1} so

H(10 meters)= **0.2 mrem/hr**

Similarly,

H(100 meters)=**0.01 mrem/hr**

C. Expression 3

Taken from reference [3]:

$$\Phi(r)=\frac{aQ}{4\pi r^2}(1-\exp(-r/\mu))\exp(-r/\lambda)$$

$a=2.8$
$\mu=5.6 \times 10^3$ cm
$\lambda=2.67 \times 10^4$ cm
Q is the source strength

Φ is in units of neutrons cm^{-2} sec^{-1} and r is in cm.

Note that reference [3] says this formula is valid for r > 50 meters. I don't know how accurate it is for smaller distances.

$$\phi(r) = \frac{2.8\ (1.25\times10^8)}{4\pi\ (1000)^2}\ (1-\exp(-1000/5.6\times10^3))\exp(-1000/2.67\times10^{4})$$

ϕ(10 meters) = 4.4 n cm^{-2} sec^{-1} I assume 1 MeV neutrons with 8.5 n cm^{-2} sec^{-1} per mrem hr^{-1} so,

H(10 meters) =**0.5 mrem/hr** and similarly

H(100 meters)=**0.004 mrem/hr**

D. Expression 4

Taken from reference 3.

As an alternative method, I extrapolate from a low energy measurement that had good geometry and knowledge of the souce term. Unfortunately it was done at only 50 MeV incident proton energy. However, if I assume that the dose rate scales with the number of neutrons produced per interacting proton and that the spectrum of scattered neutrons does not differ significantly from 50 to 250 MeV then this can give another estimate of the skyshine dose. A 50 MeV proton beam was incident on a thick aluminum target surrounded by a 12 foot high, 3 foot thick concrete wall with no roof over the enclosure. The dose was measured at several distances ranging from one yard or so out to about fifty yards. It was verified that direct radiation throught the shield wall was negligible. The shielding and targeting arrangement is not too different from our situation in IB1. From reference [3-(figure 8)], the maximum in the dose rate outside the shield wall for 50 MeV incident protons was about 120 mrem hr^{-1} μA^{-1}. This occurs about 6 yards from the shield wall. There is no indication of the distance from the target to the wall but it is probably at most a few yards. Based on figure 3.22 of Ref [1], the ratio of neutron yields at 50 MeV and 250 MeV is about 30. Thus for 250 MeV protons interacting at 2.5×10^{8} protons/sec (4×10^{-5} μamp), the estimated dose rate is:

$$H = 120 \text{ mrem hr}^{-1} \mu A^{-1} (4\times10^{-5} \mu A)(30) = \mathbf{0.14 \text{ mrem hr}^{-1}}$$

Note that an increase in the wall height to 19 feet in the measurements described in ref[3] reduced the peak dose rate from 120 mrem hr^{-1} μamp to 50 mrem hr^{-1} μamp. Thus we can expect that the dose rate outside a 9 foot high wall would be somewhat greater than the dose rate determined from the above extrapolation. However, this increase is probably no more than a factor of two.

III. Conclusions

While these estimates must be considered to have large uncertainity (i.e. a factor of 10 spread in the results for close distances), they do set the scale of dose rates to be expected from skyshine. Dose rates of the order of 0.1 to 1 mrem/hr in the area of the accelerator control room might be anticipated, depending on the loss point, measurement location, beam energy, and number of interacting protons. Fortunately, measurements can be made to determine if skyshine doses due to normal running are a problem (i. e. exceed 0.25 mrem/hr in occupied areas). Dose rates outside the IB1 building will not be a problem since these are minimally occupied areas and it seems clear that the dose rates due to normal losses will be well below 0.25 mrem/hr. Doses due to accidental losses of full intensity beam will be limited by interlocked detectors. It would be prudent to retain the option of local shielding of loss points in case dose rates due to skyshine are somewhat larger than anticipated.

References

1. H. W. Patterson and R. H. Thomas, Accelerator Health Physics, Academic Press (1973).

2. G. R. Stevenson and R. H. Thomas, "A Simple Procedure for the Estimation of Neutron Skyshine from Proton Accelerators", Health Physics 46 (1984) pp. 115-122.

3. A. Rindi and R. H. Thomas, "Skyshine - A Paper Tiger?", Particle Accelerators 7 (1975) pp. 23-39.

4. R. G. Alsmiller, Jr., J. Barish, and R. L. Childs, "Skyshine at Neutron Energies < 400 MeV", Particle Accelerators 11 (1981) pp. 131-141.

5. C. H. Distenfeld and R. D. Colvett, " Skyshine Considerations for Accelerator Shielding Design", Nuclear Science and Engineering 26 (1966) pp.117-121.